An evaluation of .06 tapered gutta-percha cones for filling of .06 taper prepared curved root canals

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Abstract

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Aim To compare the area occupied by gutta-percha, sealer, or void in standardized .06 tapered prepared simulated curved canals and in mesio-buccal canals of extracted maxillary first molars filled with a single .06 gutta-percha point and sealer or lateral condensation of multiple .02 gutta-percha points and sealer.

Methodology Simulated canals in resin blocks with either a 30° curve and radius of 10.5 mm ($n = 20$) or a 58° curve and 4.7 mm radius ($n = 20$) and curved mesio-buccal canals of extracted maxillary first molars ($n = 20$) were prepared using .06 ProFiles® in a variable tip crown-down sequence to an apical size 35 at 0.5 mm from the canal terminus or apical foramen. Ten 30° and 58° curved resin canals and 10 canals in the extracted teeth group were obturated with .02 taper gutta-percha cones and AH 26 sealer using lateral condensation. The time required to obturate was recorded. The remaining canals were obturated with a single .06 taper gutta-percha cone and AH 26 sealer. Excess gutta-percha was removed from the specimens using heat and the warm mass vertically condensed. Horizontal sections were cut at 0.5, 1.5, 2.5, 4.5, 7.5 and 11.5 mm from the canal terminus or apical foramen. Colour photographs were taken using an Olympus 35 mm camera attached to a stereomicroscope set at ×40 magnification, and then digitized using a flatbed scanner. The cross-sectional area of the canal contents was analysed using Adobe PhotoShop®. The percentage of gutta-percha, sealer or voids to the total root canal area were derived and data analysed using unpaired Student's *t*-test and the Mann–Whitney *U*-test.

Results In the 30° curved canals the levels had between 94 and 100% of the area filled with gutta-percha with no significant difference ($P > 0.05$) between the lateral condensation and single cone techniques. In the 58° curved canals the levels had 92–99% of the area filled with gutta-percha, with the single cone technique having significantly ($P < 0.05$) more gutta-percha fill at the 2.5 mm level only. In the mesio-buccal canals of the teeth the levels had between 72 and 96% of the area filled with gutta-percha with no significant difference ($P > 0.05$) between the lateral condensation and single cone technique. The time for obturation was significantly ($P < 0.05$) greater for lateral condensation compared with the single cone technique in all groups.

Conclusions The .06 taper single cone technique was comparable with lateral condensation in the amount of gutta-percha occupying a prepared .06 tapered canal. The .06 single cone technique was faster than lateral condensation.

Keywords: gutta-percha, root canal filling, single cone.

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Introduction

Three-dimensional filling of the root canal system with gutta-percha and sealer is an aim of root canal treatment with the goal to maximize the amount of solid core material and minimize the amount of

sealer (Wu *et al.* 2001). Before this can be achieved the root canal must be chemomechanically prepared to a sufficient shape and size to eradicate microorganisms within the root canal system and facilitate filling of the root canal. A tapered preparation with minimal apical enlargement is desirable to achieve maximum apical seal and still allow satisfactory irrigation of the root canal system (Coldero *et al.* 2002).

Nickel titanium (NiTi) rotary instruments used to prepare root canals in a crown-down technique prepare the canal system to the same standard as traditional techniques using hand files and the step back method (Ahlquist *et al.* 2001) and have gained rapid acceptance due to their advantages of increased speed of canal preparation and decreased operator fatigue (Thompson & Dummer 1997c). The ProFile® (Dentsply Maillefer, Ballaigues, Switzerland) system of .06 NiTi rotary files can prepare the canal to a constant taper of .06 mm per mm (Ruddle 2002) with a uniformly round space (Glosson *et al.* 1995). They can maintain the original canal shape, path, and working length with few procedural errors that facilitates root filling (Thompson & Dummer 1997c, 1998, Ponti *et al.* 2002). However, canal transportation does occur with NiTi files. Bryant *et al.* (1999) found more transportation to the outside of the curve using .04 or .06 ProFiles® in root canals with greater angle of curve. Ayar & Love (2004) reported no difference in the amount of material removed on the outer wall of 20° and 30° simulated root canals but did find more material removed from the inner aspect of the 30° group using ProFiles®.

Lateral condensation of cold gutta-percha is used by many clinicians throughout the world to fill root canals due to its simplicity and adaptability to most cases (Qualtrough *et al.* 1999), and is often used as a standard to compare new techniques (Dummer 2004). Filling root canals by lateral condensation of gutta-percha traditionally uses a master .02 taper standard gutta-percha cone followed by the addition of further accessory standard gutta-percha cones after lateral condensation of the gutta-percha with spreaders. This process is time consuming and has the potential to place undue force on the root leading to root fracture (Blum *et al.* 1998). Gutta-percha cones are now produced to match the taper of canals prepared with .04 or .06 rotary instruments. Larger taper gutta-percha can be used with warm vertical-compaction techniques or with a cold lateral-compaction technique (Wilson & Baumgartner 2003). With NiTi rotary preparation of the root canal and use of a sealer, these cones may provide three-dimensional obturation of the root canal over its whole length without the requirement for accessory cones or time spent on lateral condensation. Hembrough *et al.* (2002) compared the obturation quality and efficiency of lateral condensation with different tapered gutta-percha cones after preparation of single-rooted straight root canals with ProFile® .06 taper rotary files. They found that the use of .06 tapered gutta-percha cones was more efficient than .02 gutta-percha cones in terms of number of accessory points used, while the obturation quality (measured as the linear amount of sealer present between the gutta-percha mass and canal wall) was not significantly different for either method. Although this was a lateral condensation study they were only able to place an average of one accessory cone in the .06 cone group, effectively describing a single cone technique.

Manufacturers of matched taper points claim that they can fill tapered canals effectively as they correspond to canal shapes created by instruments of similar taper (Protaper obturation guide; Dentsply Maillefer). Preparation of a curved canal using ProFile® .06 rotary NiTi files may result in a shape that does not match the corresponding gutta-percha point due to canal transportation (Kum *et al.* 2000, Hata *et al.* 2002, Ayar & Love 2004) resulting in pooling of sealer or voids on the inner or outer walls of the curve. The matched-taper single cone technique has been advocated for obturation of curved root canals (Baumgartner & Tinkle 2002), however Dummer (2004) stated that laboratory or clinical reports must be available before these new points can be recommended. The aim of this study was to compare the area occupied by gutta-percha, sealer, or void in standardized .06 tapered prepared simulated curved canals or in mesio-buccal canals of extracted maxillary first molars filled by a single .06 gutta-percha point and sealer to lateral condensation of multiple .02 gutta-percha points and sealer.

Materials and methods

Canal preparation

Resin blocks (Sybron Endo Analytic, West Collins, CA, USA) with simulated root canals and extracted maxillary first molar teeth were assigned to the following groups:

1. Twenty resin blocks with 30° angle and 10.5 mm radius canals, determined according to Pruett *et al.* (1997). The canals were 17 mm long with the curved segment from 2.5 to 7.5 mm from the canal terminus.
2. Twenty resin blocks with 58° angle and 4.7 mm radius canals. The canals were 18.5 mm long with the curve from 2.5 to 9 mm from the canal terminus.
3. The mesio-buccal (MB) canals of 20 extracted maxillary first molars, average length of 13.8 ± 1.58 mm, angle 25.6 ± 19.7° and radius 10.22 ± 5.82 mm.

The extracted first molars were obtained via random selection from a collection at the University of Otago Dental School. The reason for extraction was not established but no teeth had undergone previous root canal treatment. All teeth were stored in formaldehyde until they were prepared. After preparation and before filling the teeth they were kept in gauze moistened in sterile saline. The canal curvature and angle were derived according to Pruett *et al.* (1997). Briefly, for the mesio-buccal roots, size 15 H files (Dentsply Maillefer) were placed in the root canal to the apical foramen, and then radiographed (60 kV, 80 mA, 0.1 s; Planmeca, Helsinki, Finland) perpendicular to their plane of maximum curvature. The radiographs and representative photographic images of the resin blocks were digitized (Nikon LS-4000 ED; Nikon Corporation, Kogaku, Japan), loaded into a personal computer and magnified to six times using PhotoShop® (Adobe Systems Inc., San Jose, CA, USA). Lines were drawn along the straight portion of the canal and from the apex to where the canal began to deviate. At the two points of deviation (as the canal began to curve) a line was drawn at 90°. Where the two lines intersected became the centre of a circle which defined the angle of curve as the arc between the two points and the radius of curve as the distance to the two intersecting points.

The working length was established by passing a size 10 K file into the canal until it could be just seen at the apical foramen using 2.6 × magnification (Orascoptic, Middleton, WI, USA) for mesio-buccal canals or until the file contacted the canal terminus in the simulated canal, the working length was determined as 0.5 mm short of this length. The simulated canals and MB root canals were then prepared with ProFile® rotary instruments using a 16 : 1 reduction handpiece (W&H, Bürmoos, Austria) in a high torque motor (Tecnika/ATR; Dentsply Tulsa Dental, Tulsa, OK, USA) set at 250 rpm. A standardized method of root canal preparation and obturation was undertaken by a single operator to reduce variations in the final result. A variable tip crown-down sequential technique was used to the working length at an apical size 35 and .06 taper (Table 1).

Table 1 Crown-down sequence for preparation of simulated and mesio-buccal canals

Profile® NiTi rotary file	Depth into canal
.06/40	3.5 mm
.06/30	5.5 mm
.06/25	9.5 mm
.06/20	12.5 mm (resin blocks)
.04/25	Working length
.06/25	Working length
.04/30	Working length
.06/30	Working length
.04/35	Working length
.06/35	Working length

Instruments were used for no more than five preparations. They were checked for unwinding after each use and discarded early if required. Copious sodium hypochlorite solution (2.5%) was used as an irrigant and delivered using a syringe (Monoject; Sherwood Medical, St Louis, MO, USA) and 23 gauge endodontic needle (Terumo, Tokyo, Japan).

Canal filling

Ten canals from each of the groups were filled using lateral condensation of gutta-percha and 10 by a single .06 tapered cone technique by the same operator. AH 26 sealer (DeTrey Dentsply, Konstanz, Germany) was selected due to its robust physical properties as the sectioning process required the sealer to lock the gutta-percha cones in place (Hembrough *et al.* 2002). Wu *et al.* (2000) determined that the minimum film thickness of AH 26 sealer between two glass slabs was 40 μm. At ×40 magnification of images this appeared as 1.6 mm of sealer which enabled recognition and analysis.

Lateral condensation

A size 35 .02 taper gutta-percha cone (Dentsply, Milford, DE, USA) was trimmed to give tugback at working length. The canal was dried thoroughly with paper points and a thin coat of sealer was applied to the walls using a size 40 Pastinject (Micro Mega, Besançon, France) in a slow-speed handpiece. A small amount of Sudan black B (Poly Scientific R&D, Bay Shore, NY,

USA) histological stain was added to the sealer for contrast in the MB roots. The master cone was then lightly coated with sealer and placed slowly into the canal to the full working length. Lateral condensation of gutta-percha was carried out using size 20 accessory cones and a NiTi D11T endodontic spreader (Dentsply Tulsa) starting at 1 mm from the working length. A NiTi spreader was selected after pilot studies, as it was able to consistently reach to 1 mm of the working length in all canal types. Lateral condensation continued until the spreader could no longer penetrate the upper limit of the canal.

Excess gutta-percha was then removed from the canal entrance using a System B instrument (EIE/Analytic, Redmond, WA, USA) and the gutta-percha mass then condensed vertically using a no.4 Machtou plugger (Dentsply Maillifer) for 30 s. The time taken for obturation was recorded.

Single cone

A size 35 .06 taper gutta-percha cone (Dentsply) was trimmed as necessary to give tugback at working length. The canal was dried and sealer applied as before. The cone was then lightly coated in sealer and placed slowly into the canal to the full working length. The excess gutta-percha filling material was removed and condensed as above and the time taken to obturate the canal was recorded.

To allow complete set of the sealer, all specimens were wrapped in moistened gauze and stored in a sealed container at room temperature for 1 week.

Assessment

An acrylic block or MB root specimen was orientated in a perspex-mounting jig to produce standardized cuts perpendicular to the axis of the main canal (Cathro & Love 2003). Sections were made using a diamond rotary saw (blade 0.2 mm thick) (Gillings-Hamco thin sectioning machine; Hamco Machines Inc. Rochester, NY, USA) with copious cold running water to minimize distortion of the root canal filling. Sections were made at 0.5, 1.5, 2.5, 4.5, 7.5 and 11.5 mm from the canal terminus or apical foramen in the MB roots.

The sections were viewed under a stereomicroscope at ×40 magnification (SZ-40; Olympus, Tokyo, Japan) using a halogen fibre-optic light source (KL-1500; Schott, Mainz, Germany). Colour photographs were taken with a single lens reflex (SLR) camera (C35AD-4; Olympus) attached to a triocular eyepiece (PM-10AK; Olympus) using 64-Tungsten Type II film (Fujichrome, Tokyo, Japan). The slides were scanned (Nikon LS-4000 ED; Nikon Corporation, Kogaku, Japan) and transferred to a personal computer (Acer Aspire; Acer Incorporated, Taipei, Taiwan). Digitized images were analysed using Adobe PhotoShop 7.0 (Adobe Systems Inc., San Jose, CA, USA) to calculate the percentage ratios of gutta-percha, sealer and voids to the total root canal area (Silver *et al.* 1999, Wu *et al.* 2001, Cathro & Love 2003).

To assure reproducibility of measurements and accuracy of the method, 10% of all sections were remeasured after 4 months by the same operator.

The data were analysed using unpaired Student's *t*-test and the Mann–Whitney *U*-test with a significance level of $P < 0.05$.

Results

The statistical analysis suggested a non-parametric distribution and therefore Mann–Whitney *U* results are reported.

Resin blocks

In the 30° curved canals the sections had between 94 and 100% of the area filled with gutta-percha with no significant difference between the lateral condensation and single cone techniques ($P > 0.05$) (Table 2). For the

Table 2 Comparison of the area of a simulated root canal occupied by gutta-percha after lateral condensation and single cone filling (30° lateral condensation versus 30° single cone)

Level	0.5 mm	1.5 mm	2.5 mm	4.5 mm	7.5 mm	11.5 mm
30° Lateral condensation	96.68 ± 5.52[a]	95.36 ± 5.91	95.29 ± 7.32	94.74 ± 3.49	96.94 ± 4.83	99.98 ± 0.50
30° Single cone	96.74 ± 6.34	97.95 ± 2.53	95.29 ± 7.32	97.16 ± 3.30	98.23 ± 1.81	100 ± 0
Student's *t*-test	0.98	0.69	0.41	0.19	0.42	0.23
Mann–Whitney *U*-test	0.18	0.54	0.44	0.10	0.88	0.07

[a]Percentage of total canal area occupied by gutta-percha.
*Statistically significant ($P < 0.05$).

Table 3 Comparison of the area of a simulated root canal occupied by gutta-percha after lateral condensation and single cone filling (58° lateral condensation versus 58° single cone)

Level	0.5 mm	1.5 mm	2.5 mm	4.5 mm	7.5 mm	11.5 mm
58° Lateral condensation	94.10 ± 6.70[a]	93.09 ± 4.02	92.07 ± 4.88	97.57 ± 3.76	99.89 ± 0.31	99.96 ± 0.12
58° Single cone	96.90 ± 3.44	96.16 ± 5.86	96.43 ± 4.39	97.30 ± 2.80	98.38 ± 2.36	99.38 ± 1.34
Student's *t*-test	0.18	0.10	0.07	0.83	0.08	0.21
Mann–Whitney *U*-test	0.44	0.09	0.04*	0.63	0.09	1.00

[a]Percentage of total canal area occupied by gutta-percha.
*Statistically significant ($P < 0.05$).

Figure 1 Representative image of a filled simulated canal at the 2.5 mm level (30° curved canal, lateral condensation).

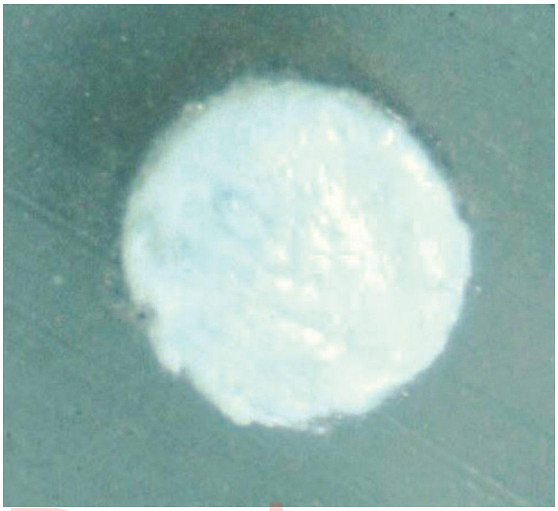

Figure 2 Representative image of a filled simulated canal at the 2.5 mm level (30° curved canal, single cone).

58° curved canals the sections had 92–99% of the area filled with gutta-percha with the single cone technique having significantly more gutta-percha fill at only the 2.5 mm level ($P < 0.05$) (Table 3; Figs 1 and 2).

When comparing lateral condensation over the two angles (Table 4; Fig. 3) the 58° block had significantly ($P < 0.05$) greater percentage fill at the 4.5 and 7.5 mm sections.

When comparing the two single cone groups (Table 5) the only significant result was at the 2.5 mm level where the 58° block had significantly ($P < 0.05$) greater percentage fill than the 30° block.

Teeth

The average angle of curvature for the lateral condensation group was 30 ± 24.18° and radius of 10.61 ± 6.2 mm. The average curvature for the single cone group was 21 ± 13.79° and radius of 9.82 ± 5.73 mm. There was no significant difference ($P > 0.05$) between the canal angle or radius between the groups.

At all levels of the MB canals the percentage of gutta-percha to total area was between 72 and 96% with no significant difference between the lateral condensation and single cone technique ($P > 0.05$) (Table 6). The lower result (72%) was at the 0.5 mm section level where sectioning and measuring were difficult due to the small size of the apical segments. The 1.5–7.5 mm results are more indicative of the actual percentage fill, the range for these levels was 84–96% (Table 6).

Time

The time for obturation was significantly greater for all lateral condensation groups ($P < 0.05$) (Tables 7 and 8).

Discussion

The objective of this study was to compare the percentage of gutta-percha, sealer or voids in a standard .06 rotary preparation of curved root canals after filling by

Table 4 Comparison of the area of a root canal occupied by gutta-percha after lateral condensation filling of simulated canals of different angles and radius (30° lateral condensation versus 58° lateral condensation)

Level	0.5 mm	1.5 mm	2.5 mm	4.5 mm	7.5 mm	11.5 mm
30° Lateral condensation	96.68 ± 5.52[a]	95.36 ± 5.91	95.29 ± 7.32	94.74 ± 3.49	96.94 ± 4.83	99.98 ± 0.50
58° Lateral condensation	94.10 ± 6.70	93.09 ± 4.02	92.07 ± 4.88	97.57 ± 3.76	99.89 ± 0.31	99.96 ± 0.12
Student's *t*-test	0.15	0.15	0.18	0.10	0.09	0.36
Mann–Whitney *U*-test	0.70	0.18	0.05	0.03*	0.01*	0.26

[a]Percentage of total canal area occupied by gutta-percha.
*Statistically significant ($P < 0.05$).

Table 5 Comparison of the area of a root canal occupied by gutta-percha after single cone filling of simulated canals of different angles and radius (30° single cone versus 58° single cone)

Level	0.5 mm	1.5 mm	2.5 mm	4.5 mm	7.5 mm	11.5 mm
30° Single cone	96.74 ± 6.34[a]	97.95 ± 2.53	95.29 ± 7.32	97.16 ± 3.30	98.23 ± 1.81	100 ± 0
58° Single cone	96.90 ± 3.44	96.16 ± 5.86	96.43 ± 4.39	97.30 ± 2.80	98.38 ± 2.36	99.38 ± 1.34
Student's *t*-test	0.95	0.33	0.59	0.92	0.82	0.18
Mann–Whitney *U*-test	0.44	0.09	0.04*	0.63	0.09	1.00

[a]Percentage of total canal area occupied by gutta-percha.
*Statistically significant ($P < 0.05$).

Figure 3 Representative image of a filled canal at the 2.5 mm level (58° curved canal lateral condensation).

lateral condensation or matched taper single gutta-percha cones. Preparation of curved root canals creates a challenge due to the problem of canal straightening by the inherent restoring forces of the file design and alloy. Straightening of the canal occurs principally at the outer wall of the apical portion of the canal (Weine *et al.* 1975) and the inner aspect of the mid-root of the canal (Abou-Rass *et al.* 1980). The geometry and amount of transportation of the prepared canal is correlated to high canal angle and small radius (Thompson & Dummer 1997a,b, Bryant *et al.* 1998a,b).

Due to the different angles and radii of curves in the simulated resin canals and extracted first molars it was expected that preparation by NiTi ProFiles® would lead to some canal transportation affecting the total cross-sectional area of gutta-percha seen. Studies on canal transportation with ProFile® rotary NiTi files (Bryant *et al.* 1998a,b, 1999, Hata *et al.* 2002, Yun & Kim 2003, Ayar & Love 2004) indicated that there may be more material removed from the outside of the canal with a greater angle of curve and more on the inner part of the canal with a smaller angle. There was a possibility that obturation using a matched-taper single cone of curved canals transported by preparation techniques would result in pooling of sealer or voids around the curve of the canal. This would be most noticeable at the curve of the canal in the cross-sectional levels between 2.5 and 7.5 mm in the resin blocks.

The results in resin blocks of the two curvatures indicated that the percentage of core material was greater than 90% at all levels. There were no significant differences except at the 2.5 mm level of the 58° group in the resin blocks where the single cone technique proved to have a higher percentage of gutta-percha (Fig. 4) and pooling of sealer could be seen at this level in the lateral condensation group (Fig. 3). This could be due to the spreader not being able to penetrate to within 1 mm of the apex because of the small radius and high angle of canal curvature when the master gutta-percha point was in place. As a result small accessory cones may not have negotiated the curve to length resulting in less gutta-percha at this

Table 6 Comparison of the area of a root canal of the mesio-buccal root of extracted upper first molars occupied by gutta-percha after lateral condensation and single cone filling

Level	0.5 mm	1.5 mm	2.5 mm	4.5 mm	7.5 mm	11.5 mm
Lateral condensation	78.12 ± 28.33[a]	84.12 ± 30.02	84.58 ± 30.12	93.62 ± 9.44	94.45 ± 4.54	85.24 ± 30.18
Single cone	72.74 ± 28.33	89.51 ± 13.07	92.29 ± 6.26	94.64 ± 4.22	96.83 ± 2.83	96.84 ± 4.69
Student's *t*-test	0.66	0.64	0.4	0.78	1.00	0.27
Mann–Whitney *U*-test	0.38	0.94	0.88	0.51	1.00	0.72

[a]Percentage of total canal area occupied by gutta-percha.
*Statistically significant ($P < 0.05$).

Table 7 Time taken (s) to obturate simulated root canals of different angles

	30° blocks	58° blocks	Student's *t*-test
Lateral condensation	282 ± 49.4	373.7 ± 59.5	0.007*
Single cone	66.5 ± 7.09	66.5 ± 7.47	1.000
Student's *t*-test	0.001*	0.001*	

*Significant result ($P < 0.05$).

Table 8 Time taken (s) to obturate mesio-buccal roots of maxillary first molar teeth

Lateral condensation	Single cone	Student's *t*-test
271 ± 24.1	60.5 ± 10.1	0.001*

*Significant result ($P < 0.05$).

Figure 4 Representative image of a filled simulated canal at the 2.5 mm level (58° curved canal, single cone).

level. To achieve the best apical adaptation with cold lateral condensation of gutta-percha the spreader should reach to within 1 mm of the working length (Allison *et al.* 1981). The use of a gutta-percha cone matched to the taper of the preparation has the advantage of a uniform mass of gutta-percha with less sealer at the canal wall interface and within the filling mass, however the gutta-percha cone will not allow spreader penetration to within 1 mm of the working length (Wilson & Baumgartner 2003).

The results indicate that preparation of root canals of different angles of curvature using ProFiles® results in a canal shape with minimal canal transportation conducive to obturation, this is in agreement with others (Imura *et al.* 2001, Peters *et al.* 2001, Ayar & Love 2004). This type of preparation allows for effective obturation using the matched-taper single cone technique which is reported as high gutta-percha fill percentages.

The amount of gutta-percha fill in the MB canals were lower (72–96%) than in the simulated canal. The lowest fill (72%) was at the 0.5 mm section level. At this level several of the sections had the gutta-percha stripped out of the canal during sectioning which may have been due to variations in the apical termination of gutta-percha to the apical foramen, overpreparation of some canals leaving very little dentine structure to support the gutta-percha when sectioned, or inadequate bonding of the sealer to the dentine wall. This resulted in the lower value of gutta-percha fill.

The lower gutta-percha fill results at the other levels in the MB canals were due to the anatomy and curvature of the root canals and a high incidence of communicating isthmus and patent second mesio-buccal canals (Fig. 5). The obturation quality would have been considerably better had both the MB 1 and MB 2 canals been prepared and filled. Previous cross-sectional studies of roots with straight canals (Wu *et al.* 2001, Jarrett *et al.* 2004) reported a higher percentage of gutta-percha fill compared with the present study, however a potentially less complex root canal anatomy and greater ease of spreader penetration and accessory cone placement in straight canals could explain the differences. The observations highlight the problem of comparing results from resin blocks to natural teeth. Resin blocks are useful for the standardization of size,

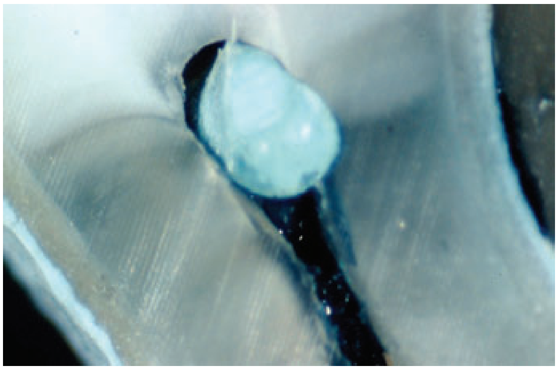

Figure 5 Relationship of an isthmus and second mesio-buccal canal to the primary mesio-buccal canal in an upper first molar tooth. The MB1 was filled using a .06 tapered single cone and sealer.

shape, curvature and taper but fail to give meaningful results on remaining dentine thickness, and root canal anatomy after root canal preparation.

The quality of a root canal filling can be assessed by a number of methods. Radiographic studies have a number of limitations imposed by the orientation of the tooth and angulation of X-ray beam which can result in an acceptable radiographic appearance of a poorly condensed or adapted root filling (Kersten *et al.* 1987). Dye and bacterial leakage studies provide comparative information on obturation techniques but many fail to show significant clinical differences and no obturation technique currently is impervious to leakage (Wu & Wesselink 1993, Camps & Pashley 2003). Bal *et al.* (2001) investigated coronal bacterial leakage of root canals prepared with .06 rotary NiTi files and then obturated with a .06 or a .02 master gutta-percha cone and sealer using lateral condensation. They found that although the spreader penetration was significantly less for the .06 master cone group, bacterial penetration between the two groups was not significantly different. Wu *et al.* (2001) used a fluid transport model to test for apical leakage and found no significant difference between lateral condensation and warm vertical condensation. The assessment of the quality of a root filling by cross-sectional analysis of the space occupied by gutta-percha, sealer and void has been advocated by a number of authors (Silver *et al.* 1999, Wu *et al.* 2000, 2001, Gençoğlu *et al.* 2002, Cathro & Love 2003). An aim of obturation is to have the maximum amount of gutta-percha filling the canal space which decreases the potential for gaps that occur due to sealer contraction or dissolution. The remaining sealer and amount of gutta-percha core allows for comparisons between studies and obturation techniques.

In this study the area of root canal filled was analysed using pixel counts available as a tool in Adobe PhotoShop. This is in contrast to other workers (Silver *et al.* 1999, Hembrough *et al.* 2002) but the same as Cathro & Love (2003). The results were able to be reproduced at a later date and all were within 0.9% of each other, and this difference would not change the significance of the results. The low variation is similar to Jarrett *et al.* (2004) who used a similar technique.

As the matched-taper single cone technique was used without any application of heat, lateral condensation was used as a comparison. In the current study the mean gutta-percha fill at 2 mm after lateral condensation in 30° resin blocks was 95.29 ± 7.32 and $92.07 \pm 4.88\%$ in 58° resin blocks and 84.58 ± 30.12 for the MB canal group. The results compare favourably with others using cold obturation techniques. Gençoğlu *et al.* (2002) found $82.66 \pm 13.14\%$ of the root canal area 2 mm from the apex filled with gutta-percha after using lateral condensation. Wu *et al.* (2001) reported 93.6% (2 mm from the apex), Jarrett *et al.* (2004) reported a mean of 93.8% and Van Gheluwe & Wilcox (1996) had mean gutta-percha fills of 96.2 ± 2.8 and $93.5 \pm 7.4\%$ using different accessory cones. In the present study, the single cone results were not significantly different from the lateral condensation results indicating that the technique was comparable with lateral condensation.

In the present study, the matched-taper single cone technique took approximately 1 min to complete for all groups and this was significantly ($P < 0.05$) faster than lateral condensation, both in the resin blocks and extracted teeth. Additionally, the 58° resin blocks lateral condensation group took significantly longer ($P < 0.05$) to fill than the 30° lateral condensation group (Table 7). Dummer *et al.* (1994) compared lateral condensation and Thermafil obturators (Dentsply Tulsa). They found that lateral condensation in curved canals took 6.29 ± 1.38 min and the Thermafil technique took 0.71 ± 0.30 min, although the Thermafil time did not allow for the heating of the obturator or severing of the shaft. In our study time was recorded from sealer placement to final vertical compaction, which took 30 s, therefore the matched-taper single cone technique could be seen as being comparable with the Thermafil technique for speed of obturation. Speed is only one of many criteria used to compare techniques but a method that is faster may lead to less operator and patient fatigue.

The use of matched-taper gutta-percha cones for cold obturation techniques relies on the original canal shape and the ability to create a tapered circular preparation. Small diameter and minimally curved mesial and distal roots of upper molars and the mesial roots of lower molars generally would be suitable for this technique. Oval shaped and larger diameter root canals would require excessive preparation for this to be effective however the use of a warm vertical condensation technique using a matched-taper cone would ensure adequate adaptation to canal irregularities.

Conclusion

Under the parameters of the study a .06 taper single cone technique was comparable with lateral condensation in the amount of gutta-percha occupying a prepared .06 tapered canal for simulated canal curvatures of 30° and 58° in resin blocks. Similar results were recorded for prepared mesio-buccal canals in extracted maxillary first molars. The .06 taper single cone technique was faster than lateral condensation.

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References

Abou-Rass M, Frank AL, Glick DH (1980) The anticurvature filing method to prepare the curved root canal. *Journal of the American Dental Association* **101**, 792–4.

Ahlquist M, Henningsson O, Hultenby K, Ohlin J (2001) The effectiveness of manual and rotary techniques in the cleaning of root canals: a scanning electron microscopy study. *International Endodontic Journal* **34**, 533–7.

Allison DA, Michelich RJ, Walton RE (1981) The influence of master cone adaptation on the quality of the apical seal. *Journal of Endodontics* **7**, 61–5.

Ayar LR, Love RM (2004) Shaping ability of ProFile and K3 rotary Ni-Ti instruments when used in a variable tip sequence in simulated curved root canals. *International Endodontic Journal* **37**, 593–601.

Bal AS, Hicks ML, Barnett F (2001) Comparison of laterally condensed .06 and .02 tapered gutta-percha and sealer in vitro. *Journal of Endodontics* **27**, 786–8.

Baumgartner JC, Tinkle JJ (2002) *Sophomore Endodontic Laboratory Manual*. Portland, OR: Oregon Health and Science University.

Blum JY, Machtou P, Micallef JP (1998) Analysis of forces developed during obturations. Wedging effect: Part II. *Journal of Endodontics* **24**, 223–8.

Bryant ST, Thompson SA, al-Omari MA, Dummer PM (1998a) Shaping ability of ProFile rotary nickel-titanium instruments with ISO sized tips in simulated root canals: Part 2. *International Endodontic Journal* **31**, 282–9.

Bryant ST, Thompson SA, al-Omari MA, Dummer PM (1998b) Shaping ability of Profile rotary nickel-titanium instruments with ISO sized tips in simulated root canals: Part 1. *International Endodontic Journal* **31**, 275–81.

Bryant ST, Dummer PM, Pitoni C, Bourba M, Moghal S (1999) Shaping ability of .04 and .06 taper ProFile rotary nickel-titanium instruments in simulated root canals. *International Endodontic Journal* **32**, 155–64.

Camps J, Pashley D (2003) Reliability of the dye penetration studies. *Journal of Endodontics* **29**, 592–4.

Cathro PR, Love RM (2003) Comparison of MicroSeal and System B/Obtura II obturation techniques. *International Endodontic Journal* **36**, 876–82.

Coldero LG, McHugh S, MacKenzie D, Saunders WP (2002) Reduction in intracanal bacteria during root canal preparation with and without apical enlargement. *International Endodontic Journal* **35**, 437–46.

Dummer PMH (2004) Root canal filling. In: Pitt Ford TR, ed. *Harty's Endodontics in Clinical Practice*, 5th edn. Edinburgh: Wright, pp. 113–36.

Dummer PM, Lyle L, Rawle J, Kennedy JK (1994) A laboratory study of root fillings in teeth obturated by lateral condensation of gutta-percha or Thermafil obturators. *International Endodontic Journal* **27**, 32–8.

Gençoğlu N, Garip Y, Baş M, Samani S (2002) Comparison of different gutta-percha root filling techniques: Thermafil, Quick-fill, System B, and lateral condensation. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **93**, 333–6.

Glosson CR, Haller RH, Dove SB, del Rio CE (1995) A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. *Journal of Endodontics* **21**, 146–51.

Hata G, Uemura M, Kato AS, Imura N, Novo NF, Toda T (2002) A comparison of shaping ability using ProFile, GT file, and Flex-R endodontic instruments in simulated canals. *Journal of Endodontics* **28**, 316–21.

Hembrough MW, Steiman HR, Belanger KK (2002) Lateral condensation in canals prepared with nickel titanium rotary instruments: an evaluation of the use of three different master cones. *Journal of Endodontics* **28**, 516–9.

Imura N, Kato AS, Novo NF, Hata G, Uemura M, Toda T (2001) A comparison of mesial molar root canal preparations using two engine-driven instruments and the balanced-force technique. *Journal of Endodontics* **27**, 627–31.

Jarrett IS, Marx D, Covey D, Karmazin M, Lavin M, Gound T (2004) Percentage of canals filled in apical cross sections-an

in vitro study of seven obturation techniques. *International Endodontic Journal* **37**, 392–98.

Kersten HW, Wesselink PR, Thoden van Velzen SK (1987) The diagnostic reliability of the buccal radiograph after root canal filling. *International Endodontic Journal* **20**, 20–4.

Kum KY, Spangberg L, Cha BY et al. (2000) Shaping ability of three ProFile rotary instrumentation techniques in simulated resin root canals. *Journal of Endodontics* **26**, 719–23.

Peters OA, Laib A, Gohring TN, Barbakow F (2001) Changes in root canal geometry after preparation assessed by high-resolution computed tomography. *Journal of Endodontics* **27**, 1–6.

Ponti TM, McDonald NJ, Kuttler S, Strassler HE, Dumsha TC (2002) Canal-centering ability of two rotary file systems. *Journal of Endodontics* **28**, 283–6.

Pruett JP, Clement DJ, Carnes DL Jr (1997) Cyclic fatigue testing of nickel-titanium endodontic instruments. *Journal of Endodontics* **23**, 77–85.

Qualtrough AJ, Whitworth JM, Dummer PM (1999) Preclinical endodontology: an international comparison. *International Endodontic Journal* **32**, 406–14.

Ruddle CJ (2002) Cleaning and shaping the root canal system. In: Cohen S, Burns R, eds. *Pathways of the Pulp*, 8th edn. St Louis, MO: Mosby, pp. 231–92.

Silver GK, Love RM, Purton DG (1999) Comparison of two vertical condensation obturation techniques: Touch 'n Heat modified and System B. *International Endodontic Journal* **32**, 287–95.

Thompson SA, Dummer PM (1997a) Shaping ability of ProFile.04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Part 2. *International Endodontic Journal* **30**, 8–15.

Thompson SA, Dummer PM (1997b) Shaping ability of ProFile.04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Part 1. *International Endodontic Journal* **30**, 1–7.

Thompson SA, Dummer PM (1997c) Shaping ability of Lightspeed rotary nickel-titanium instruments in simulated root canals. Part 1. *Journal of Endodontics* **23**, 698–702.

Thompson SA, Dummer PM (1998) Shaping ability of Mity Roto 360 degrees and Naviflex rotary nickel-titanium instruments in simulated root canals. Part 1. *Journal of Endodontics* **24**, 128–34.

Van Gheluwe J, Wilcox LR (1996) Lateral condensation of small, curved root canals: comparison of two types of accessory cones. *Journal of Endodontics* **22**, 540–2.

Weine FS, Kelly RF, Lio PJ (1975) The effect of preparation procedures on original canal shape and on apical foramen shape. *Journal of Endodontics* **1**, 255–62.

Wilson BL, Baumgartner JC (2003) Comparison of spreader penetration during lateral compaction of .04 and .02 tapered gutta-percha. *Journal of Endodontics* **29**, 828–31.

Wu MK, Wesselink PR (1993) Endodontic leakage studies reconsidered. Part I. Methodology, application and relevance. *International Endodontic Journal* **26**, 37–43.

Wu MK, Ozok AR, Wesselink PR (2000) Sealer distribution in root canals obturated by three techniques. *International Endodontic Journal* **33**, 340–5.

Wu MK, Kašt'áková A, Wesselink PR (2001) Quality of cold and warm gutta-percha fillings in oval canals in mandibular premolars. *International Endodontic Journal* **34**, 485–91.

Yun HH, Kim SK (2003) A comparison of the shaping abilities of 4 nickel-titanium rotary instruments in simulated root canals. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **95**, 228–33.